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"Landscape and Disturbance Characteristics and
the Occurance of Bull Trout and Westlope
Cutthroat Trout"
THE UNIVERSITY OF IDAHO
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**Effects of Physiography and Disturbance Regimes
on the Distribution of Bull Trout**

**Final Report
Research Joint Venture Agreement # INT-97052-RJVA**

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INTRODUCTION

The bull trout (*Salvelinus confluentus*) has declined in both abundance and range in the last 30 years (Goetz 1989). Habitat alteration is considered an important factor in its recent decline. The species is thought to be particularly sensitive to loss of channel stability, habitat complexity and cover, increased sediment, and elevated temperatures (Rieman and McIntyre 1993).

The historic range of bull trout fell within large areas prone to locally severe fire disturbance (Meehan and Bjornn 1991; Arno 1980). Historically, the pattern of favorable habitat may have been influenced by fire frequency, severity, and scale, both within small watersheds and large basins subjected to natural fire regimes (McMahon and de Calesta 1990; Minshall et al. 1990, Minshall and Robinson 1993). Persistence of bull trout population may have depended on the response of subpopulations to this pattern of disturbance, as well as recolonization from undisturbed areas and the rate of recovery of favorable habitat conditions.

The purpose of this study was to investigate the distribution of bull trout in the Selway River basin of central Idaho. Our objectives were to characterize watersheds and stream reaches which are currently being used for spawning and rearing by bull trout and compare them to watersheds and reaches without bull trout, to describe the fire histories of watersheds with and without bull trout, and to determine if the distribution of bull trout can be related to watershed fire history.

METHODS

Study Area

The Selway River drains approximately 470,000 ha, before it meets the Lochsa River to form the Clearwater River in north-central Idaho (Fig. 1). The Selway basin has a distinctly wilderness character, with more than 380,000 ha lying within the Selway-Bitterroot and Frank Church-River of No Return Wilderness areas. An additional 57,000 ha within the drainage basin are predominantly roadless. Elevations range from 450 m near the confluence of the Selway and Lochsa rivers to 2780 m in the Bitterroot Mountains. The basin is characterized by the granitic geology of the Idaho batholith, with some Belt age gneiss and schist in the western portion. Landforms are mostly steep mountain slopes and breaklands of 50 to more than 70 percent slope along the larger streams at lower elevations, and alpine glaciated landscapes, including glacial troughs, cirques, and valley floors, at higher elevations (Fig. 2). Areas of residual upland landforms with gentler slopes and deeper soils occur in the southern portion of the basin.

Total precipitation is dominated by winter snowfall. There is a climatic gradient from northwest to southeast, as the moist maritime influence decreases. There is an autumn and winter peak in cloudiness and precipitation, but winter temperatures are moderate for the latitude as compared with locations east of the Rocky Mountains (Finklin 1983). There is a secondary peak in precipitation in late spring, and July and August are usually dry. Many

drainages are oriented from the eastern ridge on the Bitterroot Divide westward, making them susceptible to wind driven fires from the prevailing westerly winds. Runoff in lower elevation rivers usually peaks in May and June, and low flows occur in August through February.

Coniferous forest, subject to periodic lightning-ignited fire, dominates the landscape. Potential natural forest vegetation includes ponderosa pine, Douglas-fir, grand fir, western red cedar, subalpine fir, and whitebark pine (Cooper et al. 1991). Important seral species include lodgepole pine, Engelmann spruce, western larch and alpine larch.

Bull Trout and Stream Habitat Sampling

We sampled 40 watersheds within the Selway River basin during 1995-1997 (Fig. 3). For all watersheds, we determined total area, area within 300 m elevational zones, and area within 4 landform classes (rolling uplands, breaklands, glaciated lands, stream bottoms).

Within watersheds, valley bottoms were segmented by stream order, valley gradient, and valley constraint. Reaches (150 m in length) were randomly selected within valley bottom segments to sample the main stream system from headwaters to mouth, and selected tributaries. The number of reaches sampled per watershed was proportional to the total stream length. From 4 to 17 reaches were sampled per watershed, depending on size and ease of access. We also used stream inventory data from Nez Perce and Bitterroot National Forest stream surveys conducted during 1990-1997 to augment this study.

Field sampling was conducted from late July through early September during 1995-1997. Within each 150 m reach, fish were sampled by daytime snorkeling by 2-3 person crews moving from the lower to the upper end of the reach. All fish were counted by species and size class. In addition, the following physical variables were measured for each reach: stream width, depth, Rosgen channel type (Rosgen 1994), water temperature, pieces of stable-acting debris, and stream gradient.

Fire History

Fire history for the Selway Basin was mapped by fire year and severity class (low, moderate, and high) to provide a basis for inference of date and severity of fire impacts on the watershed and in riparian areas (Fig. 4, Fig. 5). Fire severity for a polygon was assigned based on percent tree canopy mortality. Fire severity classes based on tree canopy mortality were designated as high (70-100 %), moderate (30-69 %), and low (<30 %). Areas mapped as unburned within a fire perimeter for a fire of a given date showed no evidence of fire. Minimum map unit size was about 2 ha.

On mylar overlays of 1:24,000 orthophoto topographic maps, we initially sketched in fire perimeters from the forest fire history atlases, which go back to 1880. Using all available aerial photo coverage, from 1932 to 1995, we refined these fire boundaries and delineated areas of fire severity within the perimeter, and added additional areas outside the perimeter, as the photos indicated. This resulted in a map of polygons each with a burn year and severity attribute.

Concurrent with aquatic sampling, fire history maps were validated by a 2-person crew. This crew visited as many burn map polygons as feasible, focusing on stand replacement patches, because they are easier to sample at the appropriate scale. Low severity fire may show little evidence after a few years, and moderate severity fire may manifest itself in fine grain stand replacement or unburned patches, so multiple plots over a polygon would be needed to validate that year and severity class. Sample points were located to represent the most common condition within each map unit. Sampling near snorkeled reaches helped to establish fire history for that particular reach. Sampling emphasized collecting age information for representative tree size cohorts and species, to derive age since last fire and degree of stand replacement. Tree cores were taken at about 30 cm from ground level. Cores were then sanded, coated with glycerin and rings were counted with a microscope. Each core was labeled with plot number, tree number, species, diameter at breast height, age to pith and height to pith.

Data Analysis

Bull trout/Stream Habitat

We analyzed presence-absence of juvenile bull trout at the watershed scale, using discriminant analysis (Dunteman 1984). Watershed attributes were evaluated for their contribution to a discriminant function that would distinguish watersheds occupied by juvenile bull trout. A successful discriminant function could be used to classify unsampled watersheds in the basin. Data assumptions of discriminant analysis include independence, multivariate normality and equal variance-covariance matrices between groups. Transformed variables (square root or $\log_{10}$) were screened for normality using the Kolmogorov-Smirnoff test and equality of variance-covariance matrices was tested using Box's M test.

Landform, stream order-gradient composition and stream order jumping were highly correlated with one another, as were some measures of elevation with landform group. Landform group carried more information in one variable and was more powerful in discrimination than the individual stream variables, indicating that supplemental information they carried on soil depth, groundwater retention, and base flows may be important to watershed habitat suitability. Landform groups were not distributed normally among watersheds, and two landform groups (rolling uplands and breaklands) were combined for analysis, so that the composite variable became normally distributed with transformation to square root. Both of these landform groups appeared to have a high degree of association with juvenile bull trout occurrence at higher elevations. The classification function was used to classify unsampled watersheds into those likely to have high or low potential as spawning and rearing habitat. These groups of watersheds were then used to evaluate differences in geomorphic attributes and disturbance regimes.

Once watersheds had been classified for their potential to support bull trout spawning and rearing habitat, we used reach data for those watersheds to evaluate reach-scale habitat variables as predictors of occupancy by juvenile bull trout. Elevation, gradient, stream width, snorkeled area, substrate, and amounts of woody debris were analyzed using stepwise logistic regression.

Fire History

Fire history maps were intersected in ARC Grid with several other themes to develop data for subsequent analysis. We anticipated that elevation, potential vegetation, or landform might affect fire frequency, severity, and size within watersheds. We used fire history data for each watershed to estimate the effects that fire severity and frequency might have on watershed and stream habitat conditions. Equivalent clearcut area (ECA) and sediment yield models were developed as indices of watershed response to fire.

Data were divided into two periods for analysis because of the dramatic effects of fire suppression on fire frequency, size, and watershed response: 1880-1934 (55 years), and 1935-1996 (62 years). In the ECA analysis we considered only the period 1889-1934, because the data available from the early part of the fire record did not portray the residual effects of earlier fires (pre-1880) on vegetation condition.

Sediment modeling used the procedures outlined in Cline et al. (1981), and adapted for use on the Nez Perce National Forest (Harmon et al. 1992). Sediment was modeled as a function of natural conditions and disturbance-induced surface erosion (Gloss 1995). In this model, natural (base) sediment yield is assumed to derive from natural mass erosion, channel erosion, and transport of sediment stored in the channel, and on-site surface erosion rates vary with age of disturbance. Fire effects on sediment production are modeled as declining to zero after five years (Cline et al. 1981). Adjustments in erosion rates are made for geologic materials, severity of the disturbance, and slope. The amount of on-site erosion delivered to a stream channel is based on slope steepness, slope shape, and drainage dissection. The amount of natural and disturbance-induced sediment that, once delivered to a channel, is routed to a specified reach in the watershed, is based on watershed area. Unit area sediment yield is assumed to decrease as watershed size increases, due to storage in the channel and floodplain.

Equivalent clearcut area is a procedure that is used as an index of effects of disturbance on stream flow (King 1989). As used here, it does not model water yield increases directly, but simply summarizes the degree of tree canopy removal as a consequence of fire area and fire severity. Subsequent declines in ECA are modeled as a function of vegetation recovery and the rate depends on the potential vegetation at the disturbance site. The utility of the ECA concept depends on the assumption that increases in high flows follow the removal of forest canopy and that these increases may accelerate channel erosion.

We calculated ECA and percent sediment over base for all the watersheds in the basin from 1880 to 1996, considering only fire disturbance. Human ignited prescribed fires were not considered. Fire frequency was measured as the number of fires within each watershed during the period. ECA regime was measured as the number of years during the period that each watershed was in an ECA class of ≤ 10 percent, >10 -20 percent, >20 -50 percent or more than 50 percent. Sediment regime was measured as the number of years during the period that each watershed was in a sediment condition class of ≤ 5 percent over base, >5 -10 percent, >10 -20 percent, >20 -50 percent, or >50 percent.

Because the data on fire frequency, ECA and sediment condition classes did not always meet normality and homogeneity of variance assumptions, we used the Kruskal-Wallis test to assess the relationship of period, terrain, potential vegetation, and elevation class to fire frequency, severity and watershed response (as indexed by ECA and sediment regimes). Fire frequency was measured as the number of fires in each watershed during the period or the number of fires per 100 years in the watershed.

We used 3 classifications of watersheds to evaluate fire disturbance regimes:

- 1) Bull trout spawning and rearing watersheds (observed or predicted),
- 2) Low elevation watersheds (mean elevation ≤ 1600 m) without observed or predicted spawning or rearing habitat potential, and
- 3) High elevation watersheds with no predicted or observed spawning or rearing potential.

Mann-Whitney U-tests were used to evaluate whether fire frequency, ECA, and sediment regimes differed among these classes. Separate analyses were run for the periods 1880-1934 and 1935-1996.

RESULTS

Potential bull trout spawning and early rearing habitat

We found bull trout in 16 of 40 sampled watersheds. The 16 watersheds where bull trout were detected differed significantly from the 24 watersheds where bull trout were absent (Table 1). Occupied watersheds were characterized by higher elevation, greater breakland and upland area, and a greater abundance low and moderate gradient 2nd-4th order streams. Occupied and unoccupied watersheds did not differ significantly in size.

A discriminant function analysis using area in breakland and upland landforms above 1200 m elevation and area in elevation less than 1500 m proved to be the best predictor of bull trout presence or absence. A jackknifed classification procedure correctly classified 38 of 40 watersheds (Table 2, Fig. 4).

We sampled 147 reaches in the 16 watersheds supporting juvenile bull trout (Table 3). Juvenile bull trout tended to be associated with smaller streams, low and moderate gradient channels above 1200 m and larger substrate (Table 3). Stream width was the only variable in the final stepwise regression differentiating between reaches which did and did not support juvenile bull trout. Stream gradient, reach elevation, number of pieces of large woody debris, snorkeled area and substrate did not contribute significantly and were dropped from the logistic regression model.

Table 1. Comparison of watershed attributes for watersheds occupied and not occupied by juvenile bull trout using a one-way ANOVA ($n=40$).

Watershed Attribute	Watersheds occupied by bull trout ($n=16$)		Watersheds not occupied by bull trout ($n=24$)		F	<i>p</i>
	Mean	95 % C.I.	Mean	95 % C.I.		
Watershed area (ha)	6982	5415-9001	6607	5649-7727	0.17	0.684
Watershed area >1200 m (ha)	5342	5330-8849	6868	4404-6480	2.80	0.102
Abundance of 2nd-4th order low and moderate gradient habitat >1200 m (cells)	865	634-1179	372	254-543	11.02	0.002
Breakland and upland area >1200 m elevation (ha)	4483	3121-6092	2252	1642-2957	10.94	0.002
Mean elevation (m)	1912	1827-1996	1613	1530-1696	25.60	0.000
Area >1500 m elevation (ha)	5277	4106-6783	3199	2474-4137	24.80	0.000
Area <1500 m elevation (ha)	427	158-827	1952	1456-2521	7.72	0.008

Table 2. Classification of watersheds based on a jackknifed discriminant function procedure.

Potential for bull trout spawning and early rearing habitat	Predicted Group membership		
	Unoccupied	Occupied	Total
Sampled - Unoccupied	23	1	24
Sampled - Occupied	1	15	16
Percent Unoccupied	95.8	4.2	100.0
Percent Occupied	6.3	93.8	100.0
Ungrouped cases	85.4	14.6	100.0

Table 3. Summary statistics for 147 reaches in 16 watersheds with and without juvenile bull trout. Differences between reaches with and without bull trout were determined using a Mann-Whitney *U*-test.

Variable	Juvenile bull trout	Mean	Range	<i>p</i>
Width (m)	Present	5.9	1.5-12.3	0.041
	Absent	8.1	0.8-21.9	
Gradient (%)	Present	3.7	<1-10	0.938
	Absent	4.1	1-20	
Elevation (m)	Present	1554	1096-1881	0.016
	Absent	1404	865-1869	
Substrate (mode)	Present	cobble	gravel-boulder	0.034
	Absent	cobble	sand-boulder	
Snorkeled area (m ²)	Present	1008	37-3425	0.252
	Absent	205	20-9180	
Wood debris (# of pieces/150 m)	Present	25	2-95	0.040
	Absent	22	0-104	

Wildfire and watershed response indicators in the basin

Fire frequency

Fire occurred in each watershed at least once from 1880-1934 (Fig. 5). The mean fire interval at the watershed scale was about 15 years, and varied from one to 10 fire occurrences per watershed in the 55 year period. From 1935 to 1996, the mean fire interval in each watershed was every 36 years, more than twice as infrequent as in the early period (Fig. 6). Fire frequency varied from 0 to 8 times per watershed in the 62-year period.

Differences in fire frequency were generally slight among different landforms, potential vegetation types, and elevation classes as compared to differences between the two fire periods (Table 4, Table 5). Fire incidence did vary significantly among potential vegetation types during the fire period 1935-1996, in which the number of fires in Douglas fir vegetation was significantly higher than in the other 5 vegetation types (Table 5).

Equivalent clearcut area

Fire effects on tree canopy cover, as approximated by equivalent clearcut area (ECA), varied over time. Large fires occurred over much of the Selway River basin in 1889, 1910, 1919, and 1934, and these fires were severe enough to reduce tree canopy cover in many watersheds by more than 80%. The cumulative effects of episodic large fires are illustrated in Fig. 7, which shows the percent of watersheds in each ECA class (>10-20%, 20-50%, >50%) for each year from 1880 to 1996. Peaks occurred following fires in 1889, 1910, 1919, 1934, and 1994. The mean ECA during the period 1889-1934 was 12.9%; during the period 1935-1996, it was 8.4%.

Sedimentation

The cumulative effects of large fires on sediment regimes, as estimated by our modeling efforts, are illustrated in Fig. 8, in which the percent of watersheds in each sediment class are shown for the period 1880-1996. Within the 55 years of pre-fire suppression record, four fire episodes (1889, 1910, 1919, and 1934) resulted in more than 10 percent of the watersheds sustaining 10 to more than 50 percent increases in sediment over natural sediment rates. Sediment delivery as estimated after one severe fire (1919) is shown in Fig. 9 to illustrate the potential impacts of a large fire on sediment loading. Approximately 14 percent of the watersheds show sediment regimes of greater than 50 percent over natural rates for that year. About 26 percent of the watersheds were above 20 percent higher than natural sediment rates in 1919. For most years after 1935, however, the effects of fire on sedimentation rates are estimated to be small, with rates increasing no more than 5 percent over base sedimentation rates in most watersheds.

Table 4. Descriptive statistics for fire incidence among watersheds stratified by landform, potential vegetation, and mean elevation ($n = 81$).

Stratum	Fire period	Mean # fires per 100 years	Range
Landform			
Uplands	1889-1934	8.2	1.8-14.5
	1935-1996	2.4	1.6-3.2
Breaklands	1889-1934	7.3	1.8-18.2
	1935-1996	2.9	0-11.3
Alpine glaciated lands	1889-1934	5.5	1.8-9.1
	1935-1996	3.4	0-12.9
Potential Vegetation			
Douglas-fir	1889-1934	6.2	3.6-10.9
	1935-1996	5.9	0-12.9
Grand fir	1889-1934	7.3	3.6-18.2
	1935-1996	1.5	0-6.5
Western red cedar	1889-1934	7.8	5.5-10.9
	1935-1996	1.2	0-3.2
Moist subalpine fir	1889-1934	6.3	1.8-10.9
	1935-1996	2.0	0-8.1
Dry subalpine fir	1889-1934	7.1	1.8-14.5
	1935-1996	3.5	0-8.1
Subalpine fir/whitebark pine	1889-1934	3.6	----
	1935-1996	1.6	0-3.2
Elevation			
≤ 1600 m.	1889-1934	7.6	3.6-18.2
	1935-1996	2.9	0-11.3
> 1600 m.	1889-1934	5.7	1.6-12.9
	1935-1996	2.8	0-12.9

Table 5. Kruskal-Wallis test for differences in fire incidence in watersheds grouped by dominant landform, potential vegetation, and mean elevation ($n = 81$).

	Fire Period	Chi-square	<i>df</i>	<i>p</i>
Landforms (3 strata)	1889-1934	6.089	2	0.048
	1935-1996	2.298	2	0.317
Potential Vegetation (6 strata)	1889-1934	5.827	5	0.323
	1935-1996	19.753	5	0.001
Elevation (2 strata)	1889-1934	2.531	1	0.112
	1935-1996	0.057	1	0.811

Table 6. Fire frequency in watersheds with high and low potential for supporting bull trout spawning and rearing. Watersheds with high and low potential were compared using a Mann-Whitney *U*-test.

Period	Spawning and early rearing potential	Mean # fires per 100 years	Range	<i>p</i>
1889-1934	High	6.5	1.8-14.5	0.537
	Low	6.9	1.8-18.2	
1935-1996	High	2.3	0-8.1	0.559
	Low	3.1	0-12.9	

Fire regimes in relation to bull trout spawning and rearing habitat

Fire frequency

Fire frequency did not differ between watersheds with high and low bull trout spawning and rearing potential for either the early (1889-1934) or more recent fire period (1935-1996) (Table 6). Watersheds with little potential included both low and high elevation watersheds but lacked the combination of landforms and channel system associated with occupied habitat. Because watersheds with bull trout spawning and early rearing potential are all in watersheds with mean elevation ≥ 1600 m, we also tested the subset of high elevation watersheds with high and low potential, but saw no significant differences in fire frequency ($p=0.943$ and $p=0.492$ for the early and recent fire periods, respectively).

Equivalent clearcut area

The effects of fire on tree canopy cover in watersheds with high and low potential spawning and early rearing habitat are compared in Fig. 10 and Fig. 11. The greatest impact of fire in watersheds with high potential occurred in 1919 when 45 percent of watersheds had equivalent clearcut areas of ≥ 50 percent (Fig. 10). Similar patterns were seen in watersheds with low potential, with a peak in 1919 of almost 60 percent of the watersheds with equivalent clearcut areas exceeding 20 percent (Fig. 11). In all watersheds, equivalent clearcut area declined during the period 1935-1996 as a result of fire suppression in the Selway Basin. Mean equivalent clearcut area was not significantly different in watersheds with high and low spawning and rearing potential during either the period 1889-1934 or 1935-1996 (Table 7), nor were differences seen when the analysis was limited to high elevation watersheds (Table 8). We also compared fire effects on watersheds with high and low bull trout spawning and rearing potential by calculating the percentage of time that each watershed fell within the 4 ECA classifications (Table 9). No differences between watersheds were seen in either time period.

Sedimentation

Based on our modeling efforts, the effects of fire on sedimentation rates were generally slight for watersheds with both high and low bull trout spawning and rearing potential (Fig. 12, 13). Only once during 1889-1934 did the percentage of watersheds exceeding a sedimentation rate of 20 percent over base reach as high as 40 percent of the watersheds within the basin. In fact, in only 10 of the 55 years during 1889-1934 did the percentage of watersheds with sediment condition classes of more than 10 percent over base reach as high as 6 percent of the watersheds within the basin. Since 1935, modeled sedimentation events as a function of fire disturbance have been rare and of small magnitude (Fig. 12, 13). In greater than 95% of the years 1889-1996, both watersheds with high and those with low bull trout spawning and rearing potential would have had sedimentation rates of $<5\%$ over base as a consequence of wildfire based on our modeling (Table 10). There were generally few differences in predicted sedimentation

Table 7. Comparison of mean equivalent clearcut area (ECA) in watersheds with high and low bull trout spawning potential for the periods 1889-1934 and 1935-1996 based on a one-way ANOVA ($n = 81$).

Period	Spawning and early rearing potential	Mean ECA (%)	95% C.I.	F	<i>p</i>
1889-1934	High	12	9-16	0.280	0.598
	Low	13	11-15		
1935-1996	High	6	4-8	3.593	0.062
	Low	9	8-11		

Table 8. Comparison of mean equivalent clearcut area (ECA) in watersheds at elevations >1600 m with high and low bull trout spawning potential for the periods 1889-1934 and 1935-1996 based on a one-way ANOVA ($n = 55$).

Period	Spawning and early rearing potential	Mean ECA (%)	95% C.I.	F	<i>p</i>
1889-1934	High	12	9-16	0.264	0.610
	Low	13	10-16		
1935-1996	High	6	4-8	2.881	0.095
	Low	9	7-10		

Table 9. Comparison of watersheds with high and low bull trout spawning and rearing potential, based on the percent of years in 4 equivalent clearcut area classes. The *p*-values are the result of a one-way ANOVA between watersheds with high and low potential for each ECA class.

Period	ECA class	Spawning and early rearing potential	Mean percent of years in each class	Range	<i>p</i>
1889-1934	≤10%	High	62	11-100	0.842
		Low	61	0-100	
	>10-20%	High	19	0-62	0.983
		Low	18	0-63	
	>20-50%	High	16	0-49	0.519
		Low	17	0-62	
	>50%	High	2	0-16	0.416
		Low	3	0-24	
1935-1996	≤10%	High	55	10-100	0.209
		Low	55	0-100	
	>10-20%	High	17	0-55	0.584
		Low	16	0-56	
	>20-50%	High	14	0-44	0.366
		Low	15	55	
	>50%	High	2	0-15	0.162
		Low	3	0-21	

Table 10. Comparison of watersheds with high and low bull trout spawning and rearing potential, based on the percentage of years in 5 sedimentation classes. The p -values are the result of a Mann-Whitney U-test for differences between watersheds for each sediment class ($n=81$).

Period	Sediment class (percent over base)	Spawning and early rearing potential	Mean percent of years in each class	Range	p
1889-1934	<5%	High	96	89-100	0.072
		Low	95	89-100	
	>5-10%	High	1.5	0-4	0.964
		Low	1.5	0-5	
	>10-20%	High	1.2	0-4	0.495
		Low	1.4	0-5	
	>20-50%	High	0.8	0-4	0.153
		Low	1.3	0-5	
1935-1996	<5%	High	0.5	0-2	0.105
		Low	0.9	0-4	
	≤5%	High	99.5	98-100	0.086
		Low	99	95-100	
	>5-10%	High	0.2	0-2	0.243
		Low	0.2	0-3	
	>10-20%	High	0	0	0.007
		Low	0.4	0-2	
	>20-50%	High	0.1	0-2	0.726
		Low	0.1	0-2	
	>50%	High	0.1	0-2	0.101
		Low	0	0	

Table 11. Comparison of high elevation watersheds (>1600 m) with high and low bull trout spawning and rearing potential, based on the percentage of years in 5 sedimentation classes. The *p*-values are the result of a Mann-Whitney U-test for differences between watersheds for each sediment class (*n* = 55).

Period	Sediment class (percent over base)	Spawning and early rearing potential	Mean percent of years in each class	Range	<i>p</i>
1889-1934	<5%	High	96	89-100	0.413
		Low	95	89-100	
	>5-10%	High	1.5	0-4	0.494
		Low	1.4	0-5	
	>10-20%	High	1.2	0-4	0.646
		Low	1.4	0-5	
	>20-50%	High	0.8	0-4	0.296
		Low	1.3	0-5	
1935-1996	<5%	High	0.5	0-2	0.755
		Low	0.5	0-4	
	≤5%	High	99	97-100	0.380
		Low	99	95-100	
	>5-10%	High	0.2	0-2	0.322
		Low	0.4	0-3	
	>10-20%	High	0.1	0-2	0.036
		Low	0.4	0-2	
	>20-50%	High	0.1	0-2	0.337
		Low	0.1	0-2	
	>50%	High	0.1	0-2	0.221
		Low	0	0	

rates between watersheds with high and low bull trout spawning potential when the data were analyzed using either all watersheds (Table 10) or when the analysis was limited to high elevation watersheds (Table 11).

DISCUSSION

Watersheds that support bull trout spawning and rearing ranged in size from 500 to 9000 ha, and all had mean elevations greater than 1600 m. Their geographic setting was often characterized by rolling uplands and high elevation breaklands, although glaciated canyons are more common at higher elevations in the Selway River basin. Bull trout watersheds have a greater abundance of low to moderate gradient (<2-10 percent), 2nd-4th order streams. The index of normal stream ordering pattern is higher in these settings than unoccupied watersheds, indicating a dense dendritic system of streams. This implies a high degree of contact between the stream and cold groundwater. The deeper soils of these settings provide high groundwater storage and help stabilize base flows.

Discriminant function analysis was used with coarse mappable features of landform and elevation to predict watershed suitability for spawning and early rearing of bull trout, based on observed occupancy. Landforms provided important information on the abundance of channel features associated with young bull trout. Landforms have the advantage of high efficiency in characterizing suites of highly correlated environmental variables, including stream density, channel pattern, abundance of certain order-gradient classes, and hydrologic information, including soil depth, slope, channel stability, and hydrologic disturbance regimes, including runoff timing and peaks, susceptibility to rain on snow flooding and debris torrents. Within watersheds, juvenile bull trout tended to be associated with reaches in smaller streams, low and moderate gradient channels, elevations above 1100 m, and gravel to small boulder substrate. Stepwise-logistic regression indicated that stream width had the greatest power to predict reach occupancy.

Two other recent studies have also investigated the distribution of bull trout in relation to landscape characteristics. Rieman and McIntyre (1995) found that watershed size and stream width were important factors explaining the distribution of bull trout in the Boise River basin in southern Idaho. They suggested that larger watersheds likely have higher probabilities of recolonization and lower rates of extirpation than smaller watersheds. Although bull trout occurrence was also strongly related to stream width, Rieman and McIntyre (1995) believed that the significance of width was related to its collinearity with watershed size. They found that width explained little of the variation in bull trout distribution among reaches in occupied watersheds. Watson and Hillman (1997) surveyed 93 streams for bull trout in 18 drainages in Washington, Idaho, and Montana. Although a number of factors influenced distribution and abundance at finer scales (eg., undercut banks, boulder/cobble substrate, riparian vegetation), bull trout occurrence was more consistently related to coarse-scale variables. Valley bottom type was one of the most important variables describing the distribution of bull trout. Our study also highlights the importance of landscape-level variables in predicting the occurrence of bull trout.

Fires occurred in each watershed at least once during the period 1880-1996. Most of the total area burned in the Selway River basin, however, occurred in four years: 1889, 1910,

1919, and 1934. Fires were much less extensive after 1935, probably due to fire suppression, climate, and the extensive area burned earlier in the century. The fires prior to 1935 also contributed more substantially to sediment loads based on our models than did fires after 1935.

We did not detect strong relationships between bull trout distribution and fire regimes. Associations between wildfire and bull trout are complex and fire effects on fish are undoubtedly difficult to identify. Rieman et al. (1995) has suggested that refounding of extirpated local populations can occur within three years after severe fires. This recovery is facilitated by recolonization from less severely burned adjacent reaches and watersheds. Thus, the effects of fires may be both direct and indirect within stream reaches and they may also be relatively short-term. Intense fires may directly influence habitat conditions for bull trout by altering sediment composition and riparian vegetation, but they may also indirectly influence the recovery of populations if the extent of the fires are great enough to also affect adjacent and potential source populations.

Fires prior to 1935 were often severe and burned large areas of the Selway River basin. The severity and vast extent of these burns across much of the basin may well have had an impact on subpopulations of bull trout. These impacts, if they occurred, may not be detectable now, because the last 65 years have been characterized by a general absence of severe fire and, presumably, sufficient time has elapsed for recolonization to have occurred, even in watersheds that were subject to very intense fires and their consequences.

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Figure 1
Selway Basin
Vicinity Map and
Sampled Watersheds

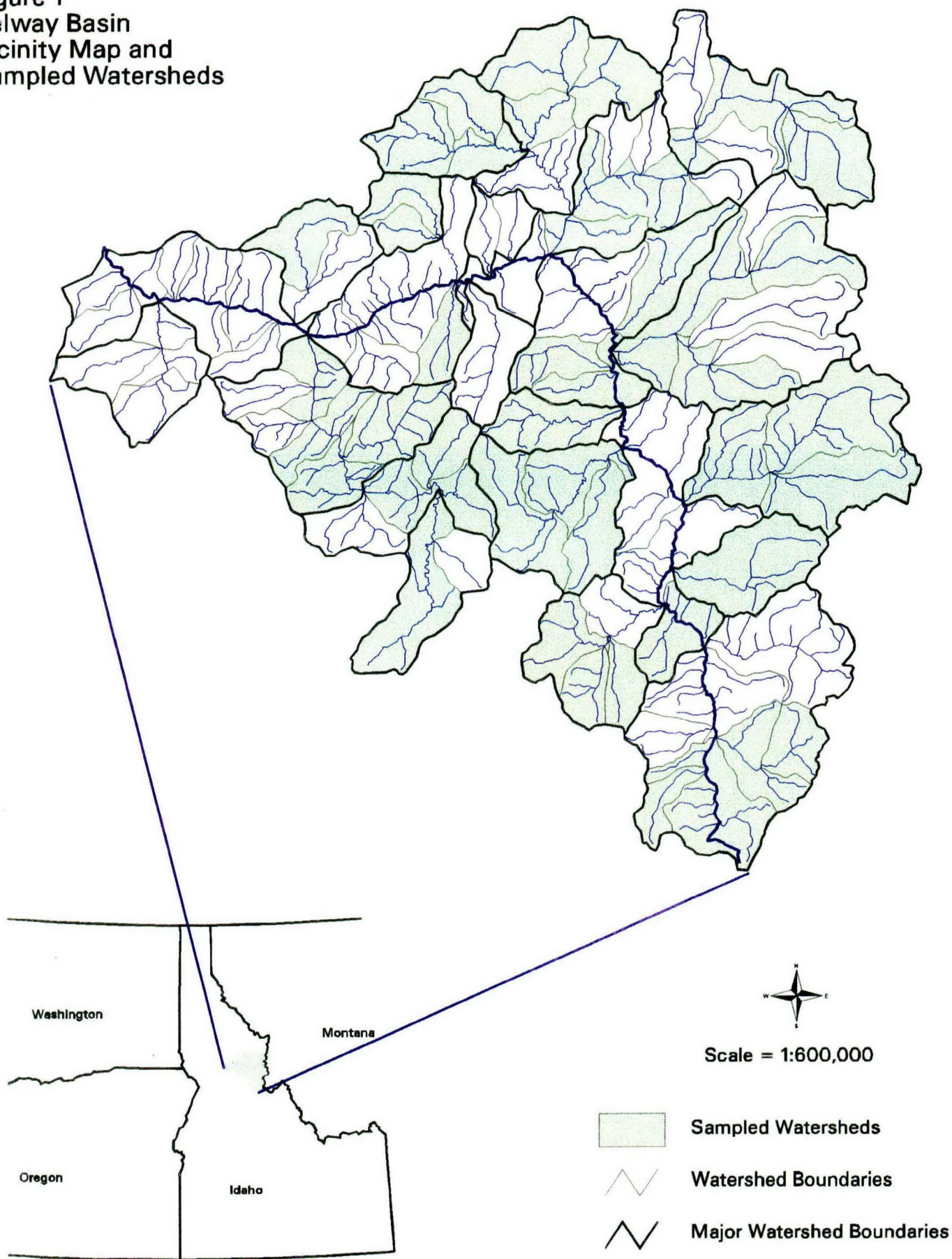


Figure 2
Selway Basin
Landform Groups

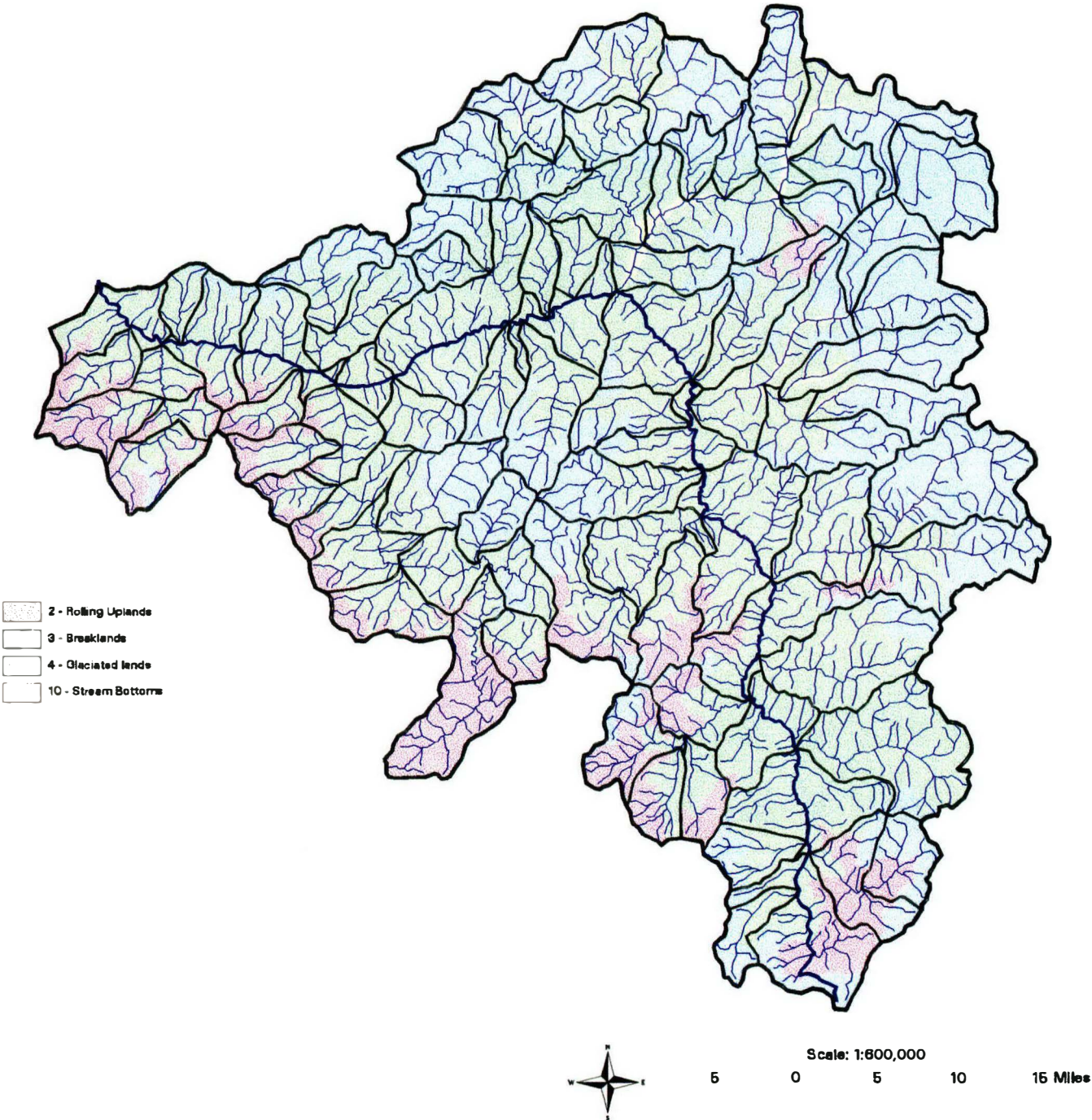


Figure 3
Selway Basin
Sample Stream Reach Locations with Juvenile Bull Trout

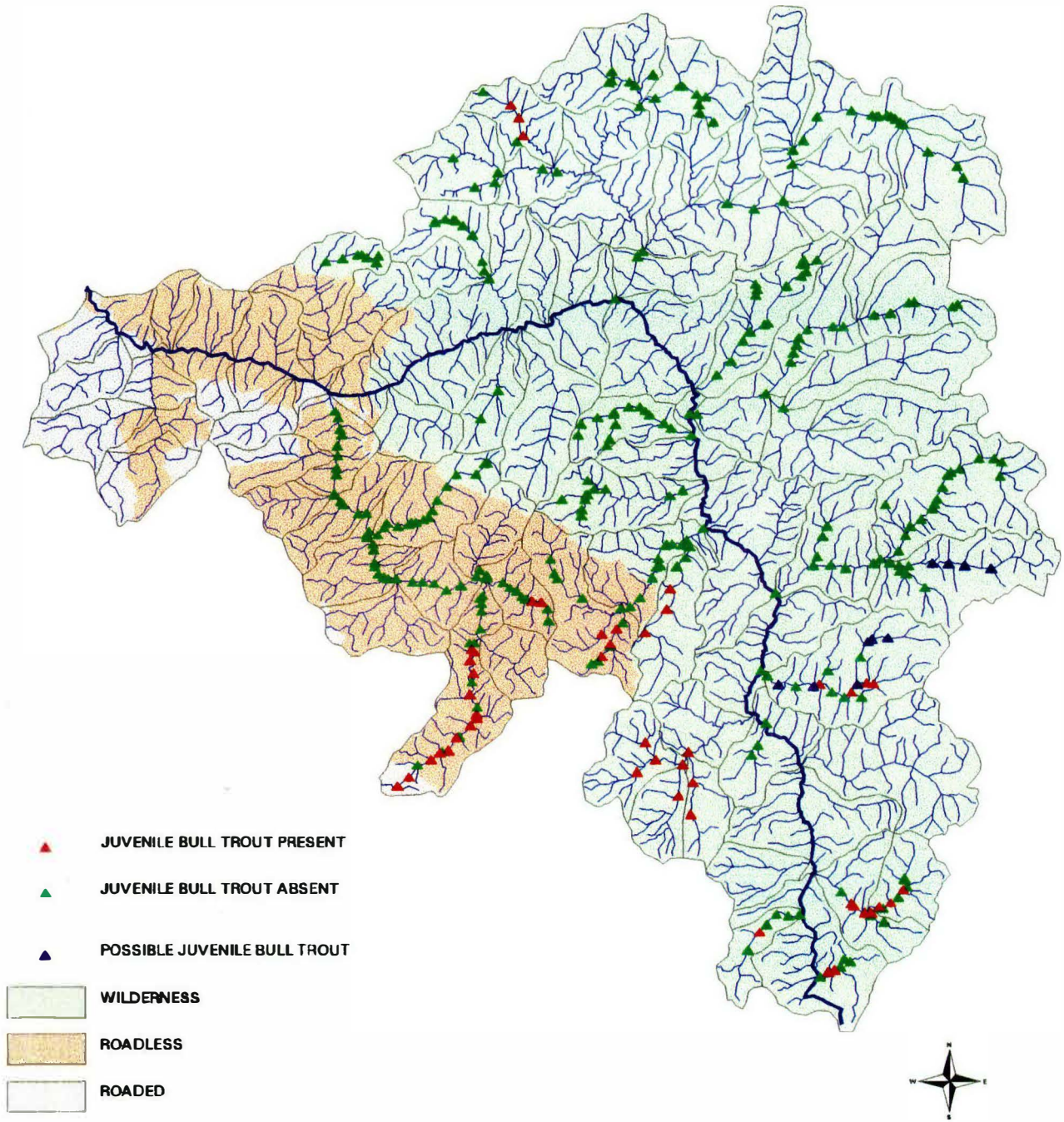


Figure 4

Selway Basin

Watersheds with Potential Bull Trout Spawning and Early Rearing Habitat

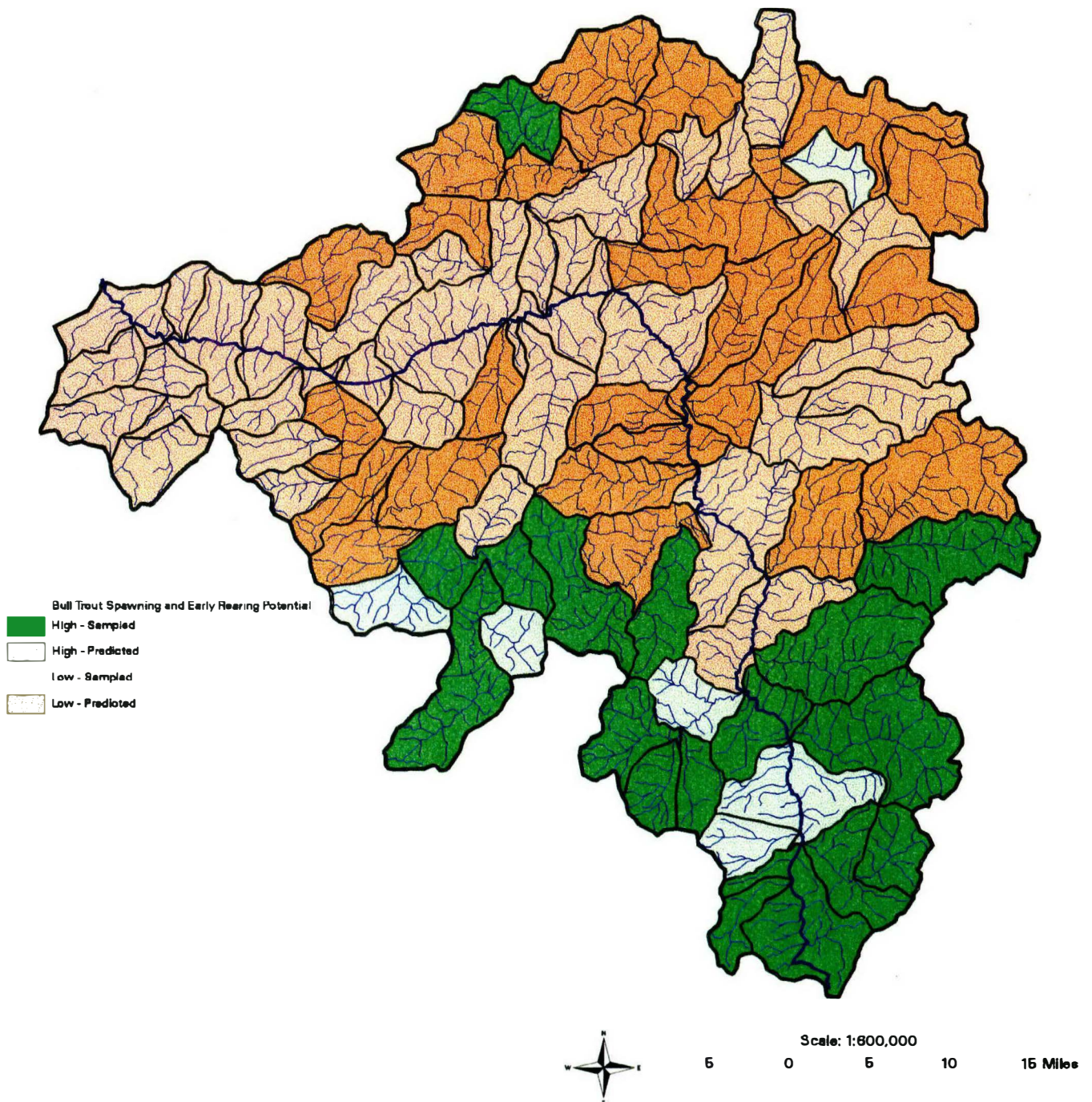


Figure 3
Selway Basin
Fire History: 1870 to 1934 by decade

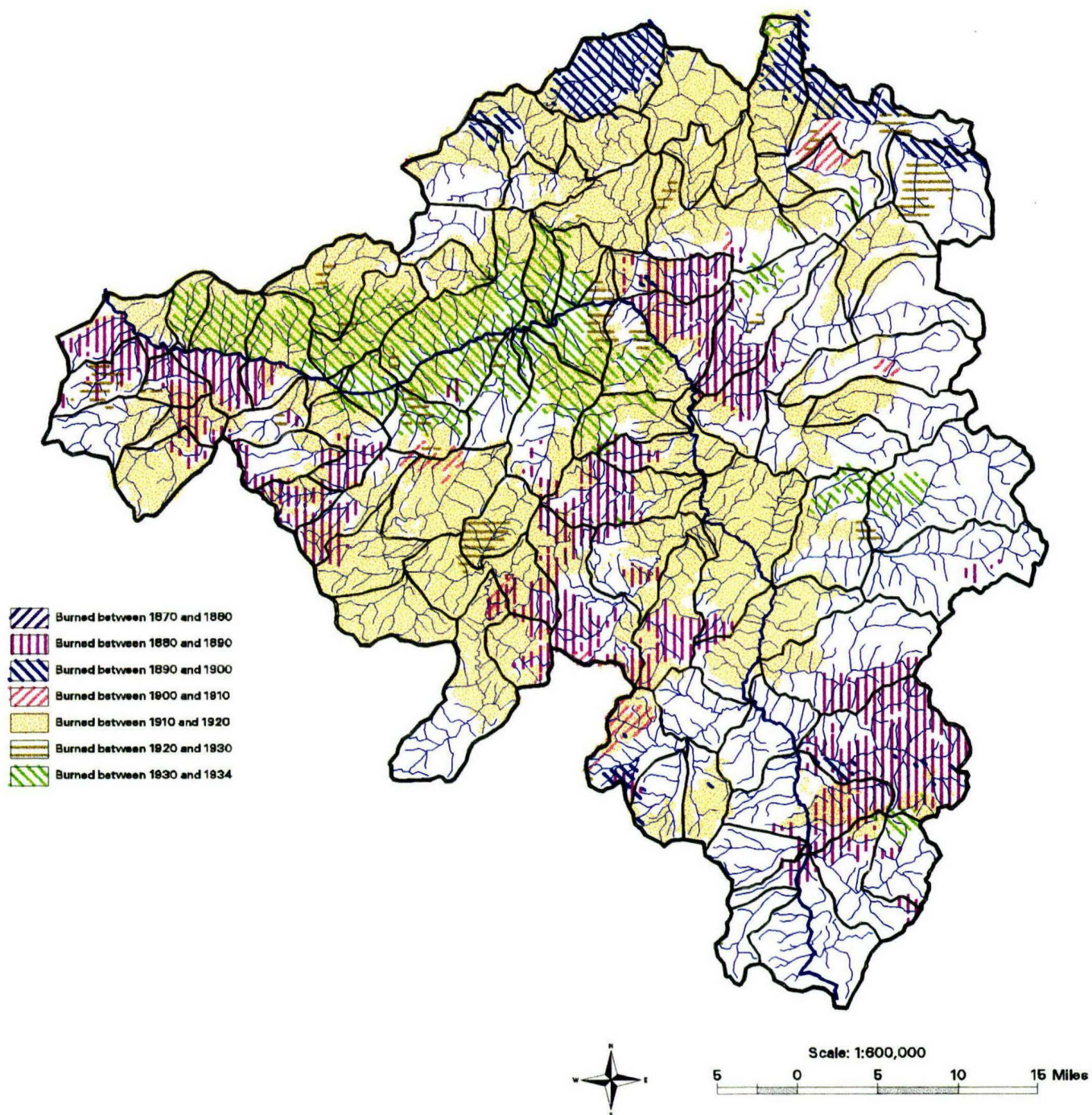


Figure 6
Selway Basin
Fire History: 1935 to 1996 by decade

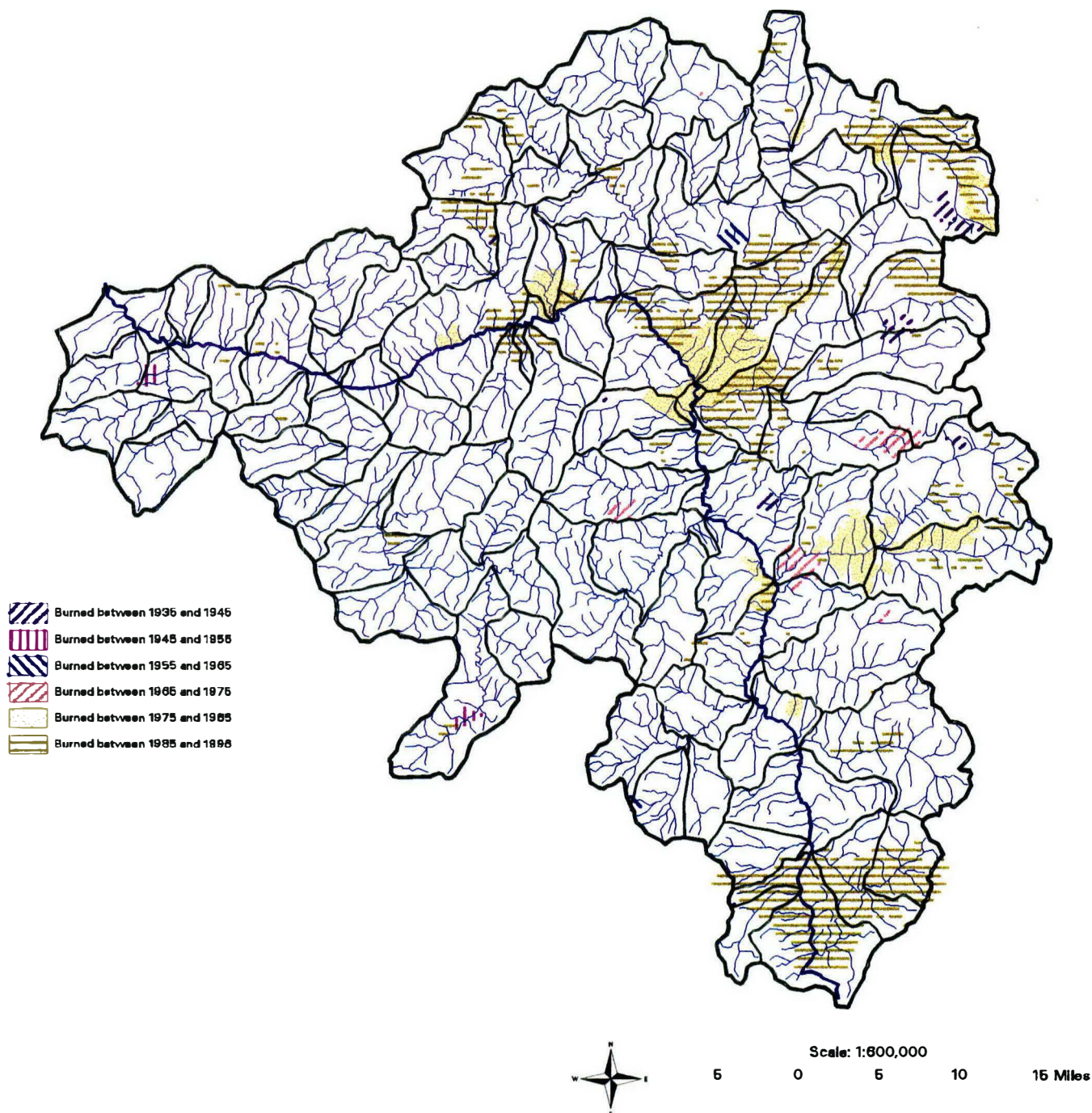


Figure 7
Selway Basin: Equivalent Clearcut Area Condition
Classes across Watersheds over Time: 1880-1996

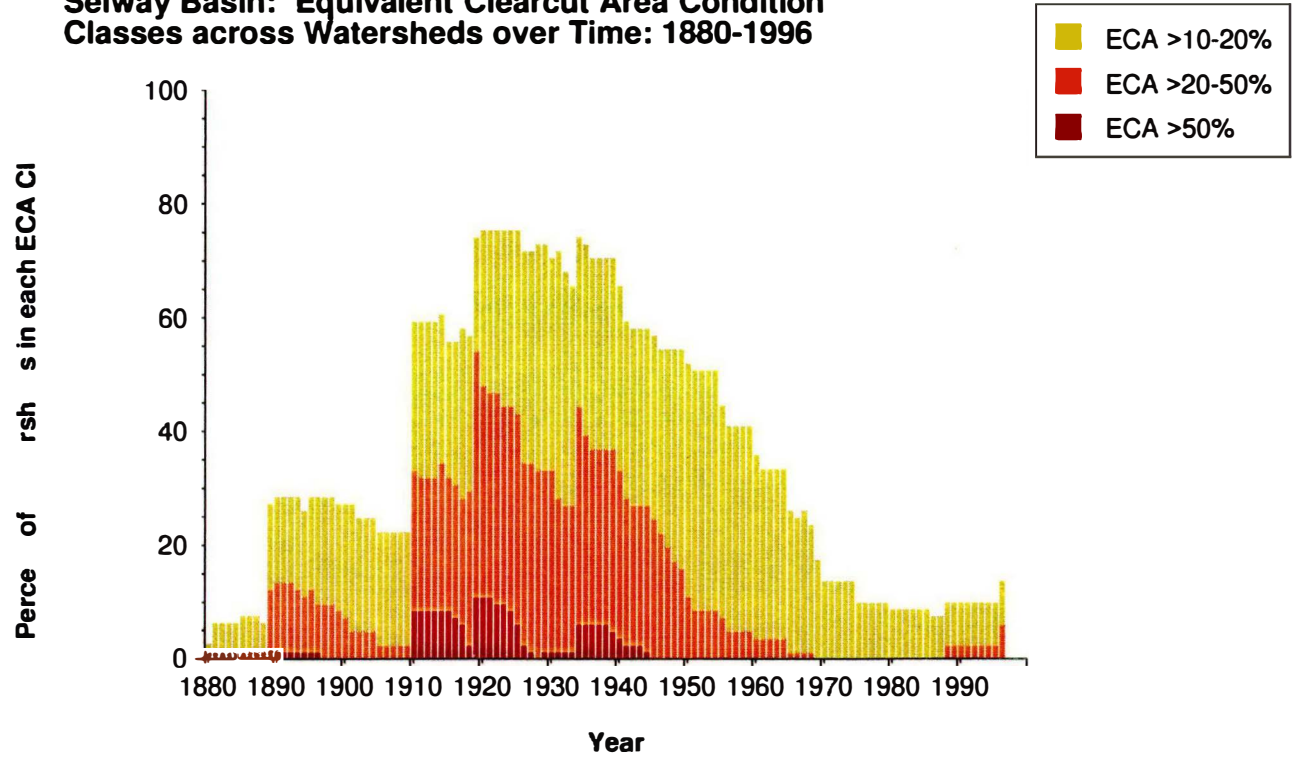
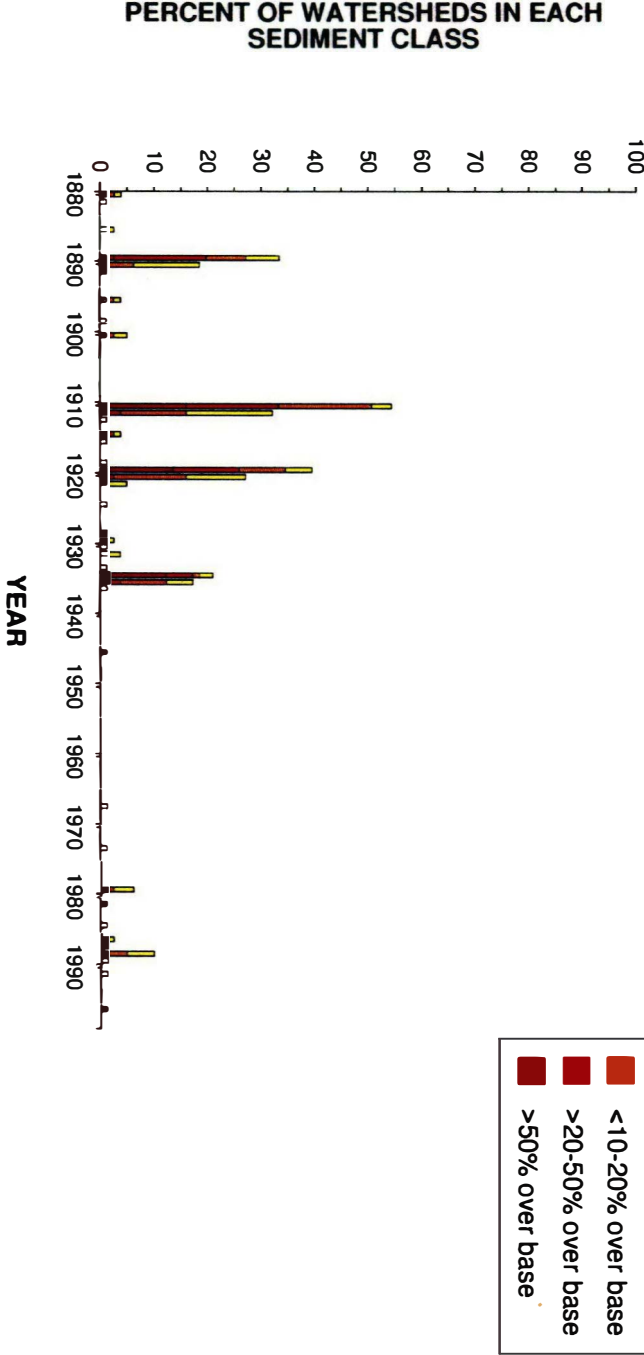


Figure 8
Percent of Watersheds in Sediment Condition Classes over Time
in Response to Fire: 1880-1996



- Figure 9
• Selway Basin
Watershed Condition: Percent Sediment over Base
Year: 1919 (fire only)

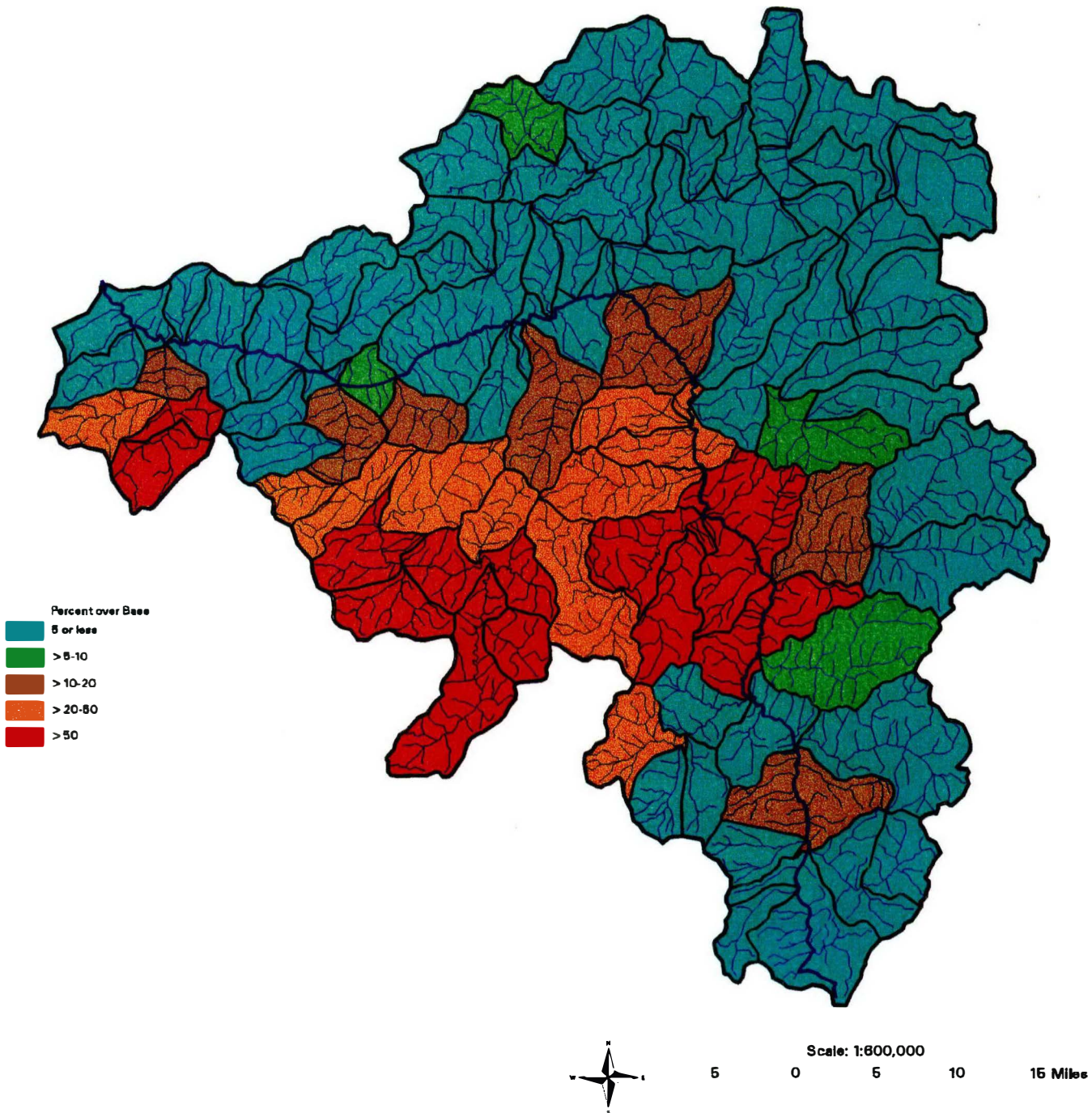


Figure 10
Selway Basin: Equivalent Clearcut Area Condition
Classes across Watersheds over Time: 1889-1996
Watersheds having juvenile bull trout potential

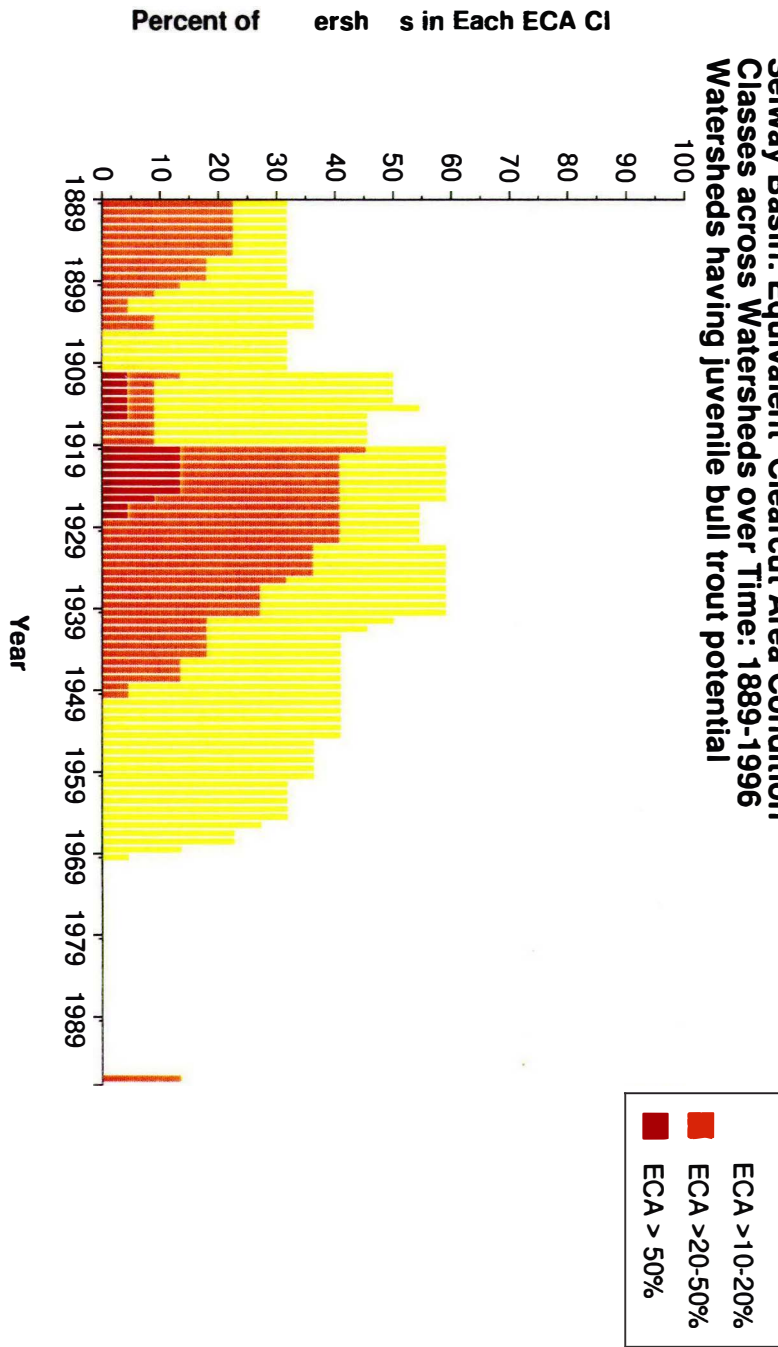


Figure 11
Selway Basin: Equivalent Clearcut Area Condition
Classes across Watersheds over Time: 1889-1996
Watersheds with little juvenile bull trout potential

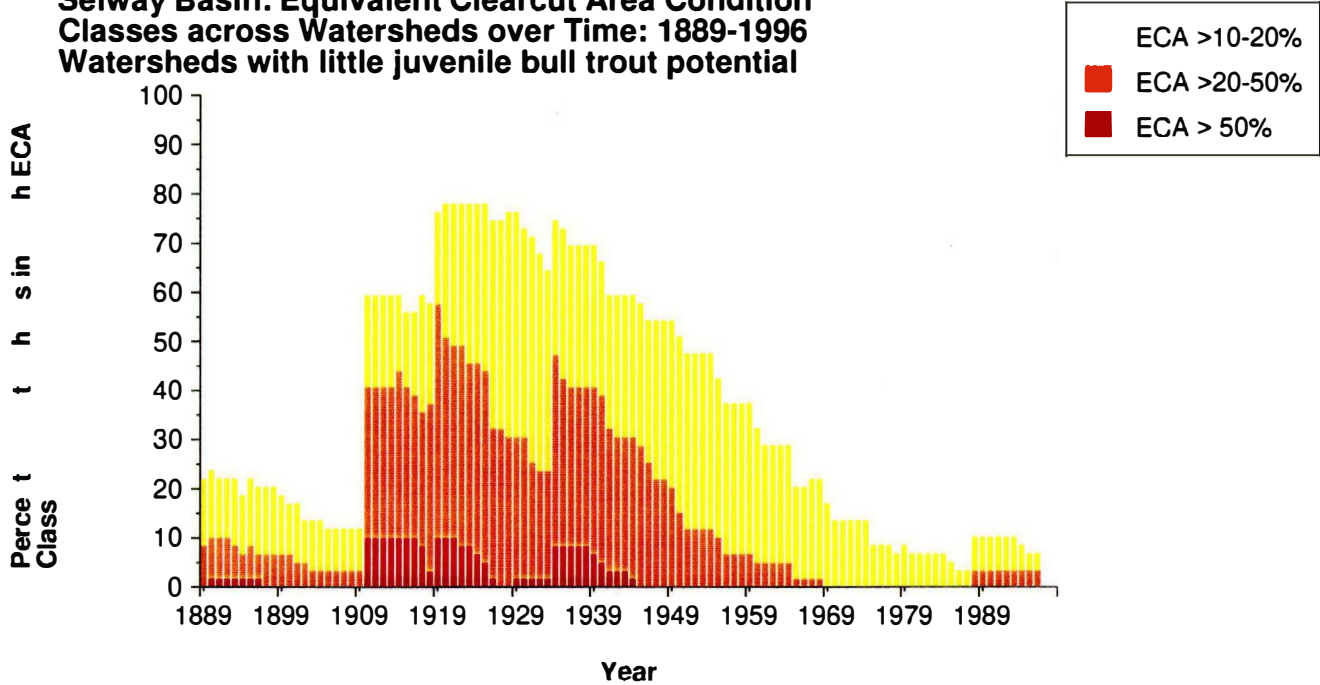


Figure 12

Percent of Watersheds in Sediment Condition Classes over Time in Response to fire: 1880-1996

Watersheds having juvenile bull trout potential

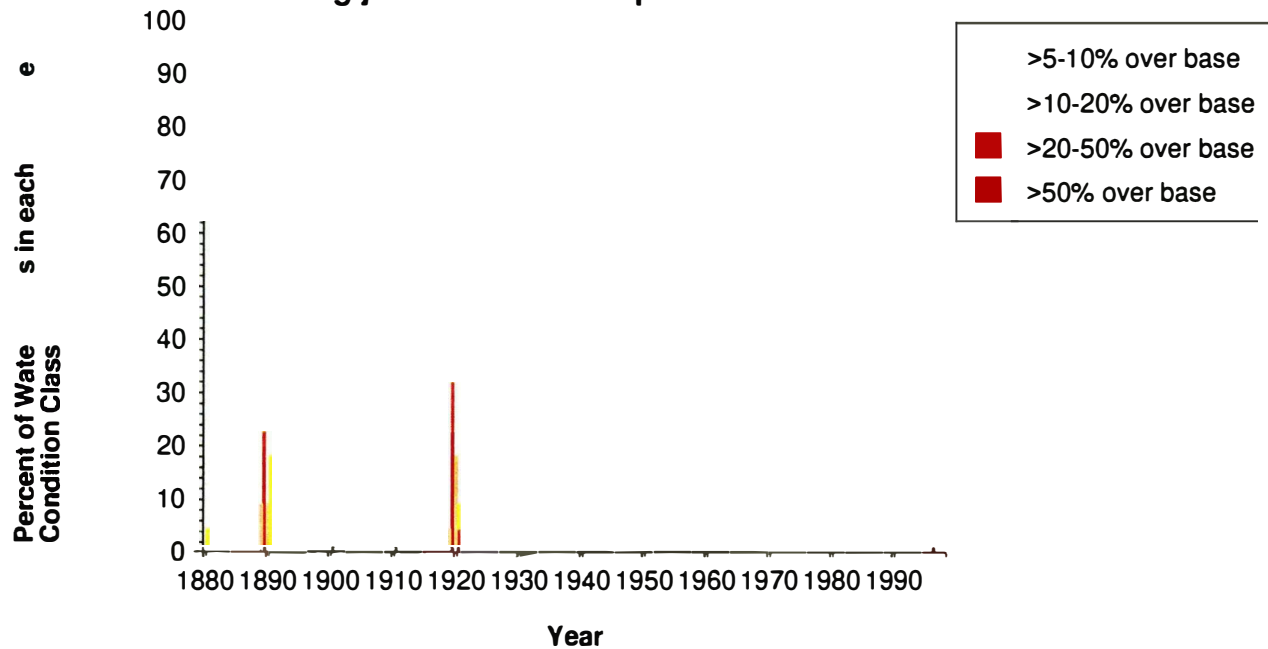


Figure 13
Percent of Watersheds in Sediment Condition Classes over Time
in Response to Fire: 1880-1996
Watersheds with little juvenile bull trout potential

